

but not be limited to, charge coupled device (CCD) and/or complementary metal oxide semiconductor (CMOS) sensor elements to capture infrared images (IR) or other non-visible electromagnetic radiation. In some embodiments, camera 102 includes more than one image sensor to capture multiple types of images. For example, camera 102 may include both IR sensors and RGB (red, green, and blue) sensors. In certain embodiments, camera 102 includes illuminators 105 for illuminating surfaces (or subjects) with the different types of light detected by image sensor 103. For example, camera 102 may include an illuminator for visible light (e.g., a “flash illuminator”) and/or illuminators for infrared light (e.g., a flood IR source and a speckle pattern projector). In some embodiments, the flood IR source and speckle pattern projector are other wavelengths of light (e.g., not infrared). In certain embodiments, illuminators 105 include an array of light sources such as, but not limited to, VCSELs (vertical-cavity surface-emitting lasers). In some embodiments, image sensors 103 and illuminators 105 are included in a single chip package. In some embodiments, image sensors 103 and illuminators 105 are located on separate chip packages.

[0028] In certain embodiments, image sensor 103 is an IR image sensor used to capture infrared images used for face detection and/or depth detection. For face detection, illuminator 105A may provide flood IR illumination to flood the subject with IR illumination (e.g., an IR flashlight) and image sensor 103 may capture images of the flood IR illuminated subject. Flood IR illumination images may be, for example, two-dimensional images of the subject illuminated by IR light. For depth detection or generating a depth map image, illuminator 105B may provide IR illumination with a speckle pattern. The speckle pattern may be a pattern of light spots (e.g., a pattern of dots) with a known, and controllable, configuration and pattern projected onto a subject. Illuminator 105B may include a VCSEL array configured to form the speckle pattern or a light source and patterned transparency configured to form the speckle pattern. The configuration and pattern of the speckle pattern provided by illuminator 105B may be selected, for example, based on a desired speckle pattern density (e.g., dot density) at the subject. Image sensor 103 may capture images of the subject illuminated by the speckle pattern. The captured image of the speckle pattern on the subject may be assessed (e.g., analyzed and/or processed) by an imaging and processing system (e.g., an image signal processor (ISP) as described herein) to produce or estimate a three-dimensional map of the subject (e.g., a depth map or depth map image of the subject). Examples of depth map imaging are described in U.S. Pat. No. 8,150,142 to Freedman et al., U.S. Pat. No. 8,749,796 to Pesach et al., and U.S. Pat. No. 8,384,997 to Shpunt et al., which are incorporated by reference as if fully set forth herein, and in U.S. Patent Application Publication No. 2016/0178915 to Mor et al., which is incorporated by reference as if fully set forth herein.

[0029] In certain embodiments, images captured by camera 102 include images with the user’s face (e.g., the user’s face is included in the images). An image with the user’s face may include any digital image with the user’s face shown within the frame of the image. Such an image may include just the user’s face or may include the user’s face in a smaller part or portion of the image. The user’s face may

be captured with sufficient resolution in the image to allow image processing of one or more features of the user’s face in the image.

[0030] Images captured by camera 102 may be processed by processor 104. FIG. 3 depicts a representation of an embodiment of processor 104 included in device 100. Processor 104 may include circuitry configured to execute instructions defined in an instruction set architecture implemented by the processor. Processor 104 may execute the main control software of device 100, such as an operating system. Generally, software executed by processor 104 during use may control the other components of device 100 to realize the desired functionality of the device. The processors may also execute other software. These applications may provide user functionality, and may rely on the operating system for lower-level device control, scheduling, memory management, etc.

[0031] In certain embodiments, processor 104 includes image signal processor (ISP) 110. ISP 110 may include circuitry suitable for processing images (e.g., image signal processing circuitry) received from camera 102. ISP 110 may include any hardware and/or software (e.g., program instructions) capable of processing or analyzing images captured by camera 102.

[0032] In certain embodiments, processor 104 includes secure enclave processor (SEP) 112. In some embodiments, SEP 112 is involved in a facial recognition authentication process involving images captured by camera 102 and processed by ISP 110. SEP 112 may be a secure circuit configured to authenticate an active user (e.g., the user that is currently using device 100) as authorized to use device 100. A “secure circuit” may be a circuit that protects an isolated, internal resource from being directly accessed by an external circuit. The internal resource may be memory (e.g., memory 106) that stores sensitive data such as personal information (e.g., biometric information, credit card information, etc.), encryption keys, random number generator seeds, etc. The internal resource may also be circuitry that performs services/operations associated with sensitive data. As described herein, SEP 112 may include any hardware and/or software (e.g., program instructions) capable of authenticating a user using the facial recognition authentication process. The facial recognition authentication process may authenticate a user by capturing images of the user with camera 102 and comparing the captured images to previously collected images of an authorized user for device 100. In some embodiments, the functions of ISP 110 and SEP 112 may be performed by a single processor (e.g., either ISP 110 or SEP 112 may perform both functionalities and the other processor may be omitted).

[0033] In certain embodiments, processor 104 performs an enrollment process (e.g., an image enrollment process or a registration process) to capture and store images (e.g., the previously collected images) for an authorized user of device 100. During the enrollment process, camera module 102 may capture (e.g., collect) images and/or image data from an authorized user in order to permit SEP 112 (or another security process) to subsequently authenticate the user using the facial recognition authentication process. In some embodiments, the images and/or image data (e.g., feature data from the images) from the enrollment process are stored in a template in device 100. The template may be stored, for example, in a template space in memory 106 of device 100. In some embodiments, the template space may